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research trends

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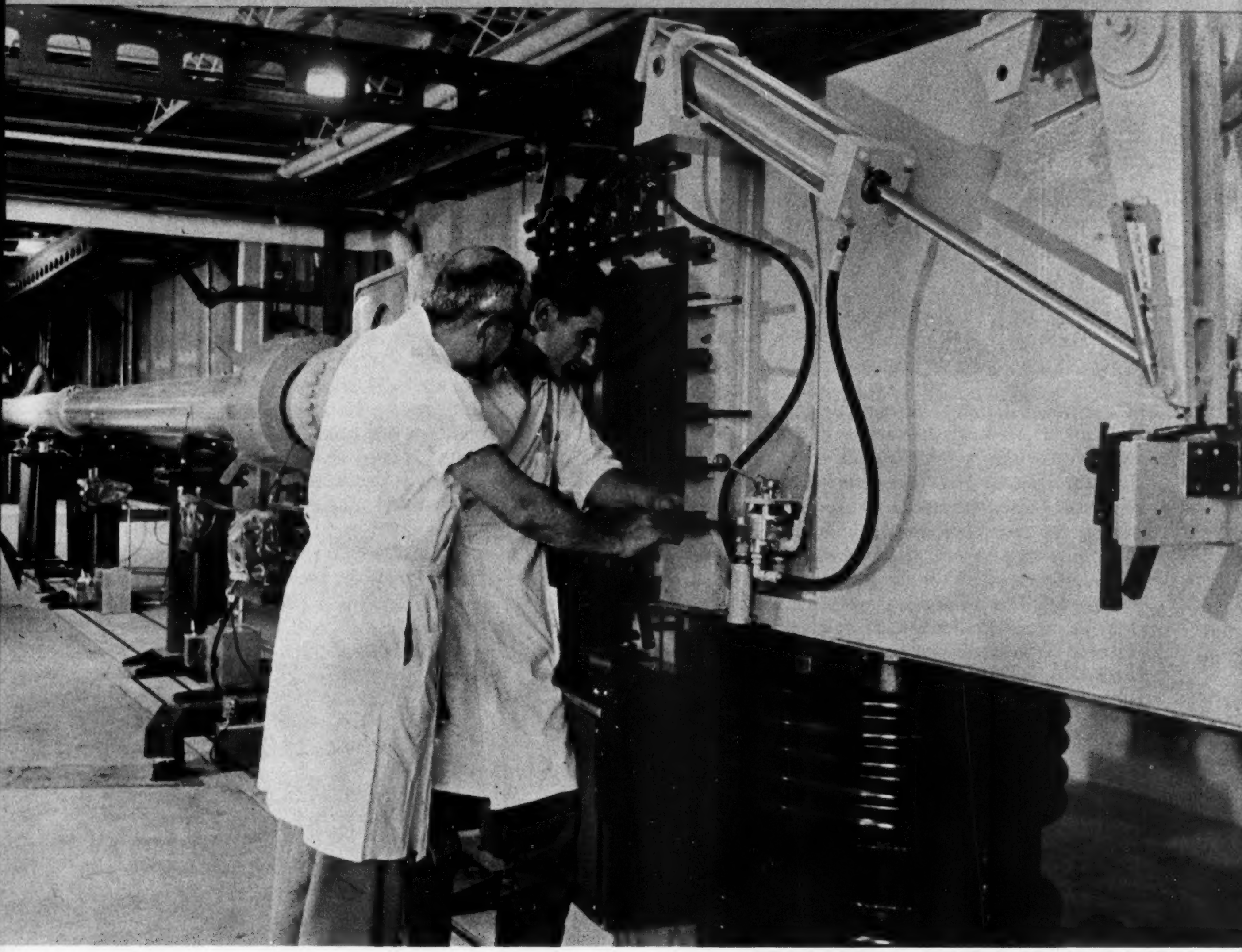


New Tool for RESEARCH . . .

by JAMES F. MARTIN

Horizons for Hypersonic Study Extended By Introduction of 24-Inch Shock Tunnel

WITH man's first ventures into the realm of hypersonic flight, came the need for tools to study this new environment. One of these tools is Cornell Aeronautical Laboratory's new 24-inch hypersonic shock tunnel, designed and constructed after more than a decade of research and experiment.

As transonic research early in the decade produced the porous wall technique, more recent effort in shock tube processes has culminated in the 24-inch hypersonic tunnel. Although a wide choice of approaches to the solution of experimental problems in high-speed flow lay before the aerodynamicist, no one facility had been

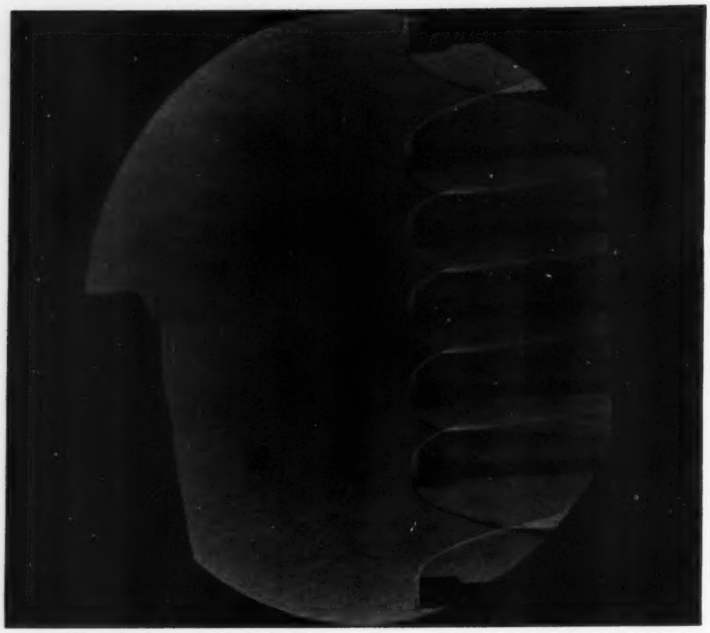


FIG. 1 — Schlieren photograph; calibration rake of pressure probes at Mach No. 8 seen through 16-inch diameter window of tunnel's test section.

conceived which would provide complete answers to these problems. The Laboratory had, since 1950, a program of research and development in the shock-tube process for obtaining the extreme conditions of pressure and temperature required to simulate flight at hypersonic speeds.

Although the shock-tube process must be examined in a time scale of thousandths of a second, imaginative research led to several breakthroughs which made feasible its utilization in a hypersonic tunnel. A shock-tube method of operation referred to as the tailored interface tube increased the available time of steady-flow conditions from the millisecond range to the 10 millisecond scale. The addition of a nozzle to the shock tube provided the required flow velocities. With the development of adequate techniques for high-speed instrumentation, the world of the millisecond began to unfold.

Early in 1958, the Laboratory directed its attention to designing a *test* facility embodying these concepts. Emphasis was placed on providing a reliable, uniform airflow, the conditions of which could be accurately known. Operation of the shock tube and its associated equipment would have to be routine in order for the tunnel to function as a reliable instrument for the study of the advanced aerodynamic and gasdynamic problems of interest not only to the Laboratory, but to the aeronautical fraternity as a whole. What, then, were the requirements of such an instrument?

Simulation Requirements

In order to generate supersonic and hypersonic velocities, a gas must flow through a nozzle, the area of which increases from a throat where sonic velocity is reached. The high-speed gas has thereby expanded and, in the process, its pressure and temperature decreased. The energy of this gas exists as velocity rather than as pressure or temperature. Room air expanded to Mach number 5 drops in temperature to -370°F, the temperature of liquid air, and to 0.0019 atmosphere of pressure. To produce Mach numbers over 5, the initial air supply must be heated to above room temperature. This is one major difference between supersonic and hypersonic wind tunnels. A hypersonic tunnel has a heated air supply. But will heating the air alone prevent condensation? We know that in some cases it will, because Mach number effects can be studied. But there are still other effects on hypersonic vehicles dependent upon pressure and temperature duplication. Viscous effects, as well as heating rates, require more than simulating hypersonic speeds. These requirements make more critical demands of the supply air. For example, at 100,000 feet altitude, the pressure is 0.01 atmosphere and the temperature is -45°F. To obtain such conditions in an airstream traveling at Mach number 8, a supply pressure of 100 atmospheres at a temperature of 4600°F is required. These are some of the problems confronting the aerodynamicist intent on designing a hypersonic test facility.

Types of Hypersonic Tunnels

A conventional blowdown tunnel consists of a compressed-air storage section, a heater, a hypersonic nozzle, and sometimes a vacuum tank. However, temperature limitations of the heater material restrict the Mach number potential of this type tunnel to about 10. In addition, considerable expense is involved in constructing a nozzle with water-cooled passages necessary to keep it from melting. By substituting helium for air a blowdown tunnel can be run without heating because the temperature at which helium liquifies (6° above absolute zero) is so very low. However, the data obtained must then be corrected to correspond to data taken in air — a procedure which presumes considerable knowledge of the flow processes being studied.

Higher temperatures are obtained with a plasma jet — a jet of heated ionized gas. In the hypersonic tunnel application the air passes through an electric arc before entering the nozzle. Plasma jets are essentially low-pressure devices and as such fail to duplicate flight conditions.

Two additional types of tunnel are the arc-discharge tunnel and the shock tunnel. An arc-discharge tunnel also makes use of a hypersonic nozzle, but it is supplied by a confined volume of air which is heated by the rapid discharge of electrical energy through an arc in the reservoir chamber. The major disadvantage of the arc tunnel is that as the heated air flows through the reservoir the supply conditions do not remain constant, but vary throughout the run. Other disadvantages are arc contamination of test gas, nozzle throat erosion,

and the consumption of oxygen to the extent that the remaining air is really not representative of the atmosphere.

Although the shock tunnel has an even shorter running time, there is a period during which supply conditions do remain constant long enough to measure the flow. The *tailored interface* tunnel developed at this Laboratory is a modification of the shock tunnel described in a previous issue of Research Trends.* The tailored interface variation of the shock tube process increases the running time of the tunnel from under one millisecond to from five to 15 milliseconds. Even though these testing times are still somewhat shorter than those of other types of hypersonic tunnels, they are still adequate to produce a steady, aerodynamic flow. Thus measurement is the problem, but the electronics engineer has long been accustomed to working with much shorter intervals of time, and ordinary test equipment is quite adequate to record in detail phenomena occurring in five milliseconds. If effects on models can be sensed in the millisecond time scale, they can be recorded. Selection, therefore, of a tunnel type could be based upon other considerations.

Design of Tunnel

Previous instrumentation development proved the feasibility of obtaining data in the time scale encountered in a shock tunnel. Several types of tests conducted in a prototype shock tunnel were successful, even though the test times were only two to three milliseconds. Length of test time, therefore, was not

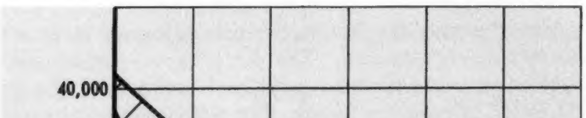


FIG. 2 — **Map of tunnel's operating range.**

FIG. 3 — **Typical burst pattern of ½-inch thick copper diaphragm. On left is scribed diaphragm before use.**

a consideration for selection of a tunnel type. First, a capability of increasing the speed range to Mach number 20 was desirable. Next, a heated air supply was needed which would not alter air conditions. (This requires a controlled heating process, because the temperature must be calculated from the process. A simple measurement of a 6000° air temperature cannot be made.) Also important was a steady, supply-air condition for the duration of the testing time. Independent control over temperature, pressure, and Mach number was necessary. Finally, the tunnel had to be capable of simulating flight conditions of pressure and temperature in the region shown by Figure 2. Because shock tubes have been used for many years to study properties of heated gases, of special importance was existing knowledge of techniques employed in the process.

The decision was made, then, to construct a shock tunnel with a capability of supplying five to 15 milliseconds of air at pressures up to 400 atmospheres and 6200°F., and with a Mach number capability of five to 20 (Figure 2).

The shock tube consists of a section of pipe (referred to as the driver tube) containing a gas at high pressure and a section of pipe (the driven tube) containing air at some lower pressure. The two sections are separated by a metal diaphragm. The diaphragm ruptures under the pressure causing the high-pressure gas to flow into the driven tube and, in the process, driving a shock wave through the air ahead of the driver gas.

Reflected Shock Wave Used

A shock wave is really a discontinuity in the pressure and temperature of the air. The air ahead of the shock wave in the driven tube has no velocity; the air behind the shock wave is flowing down the tube at the velocity of the driver gas, and has been heated and compressed in the process of acceleration. If a restriction is placed at the end of the driven tube, the shock wave is reflected. The reflected shock now brings the driver gas

*"The Wings of Icarus" by Abraham Hertzberg; *Research Trends*, Summer 1955, Vol. III, No. 2.

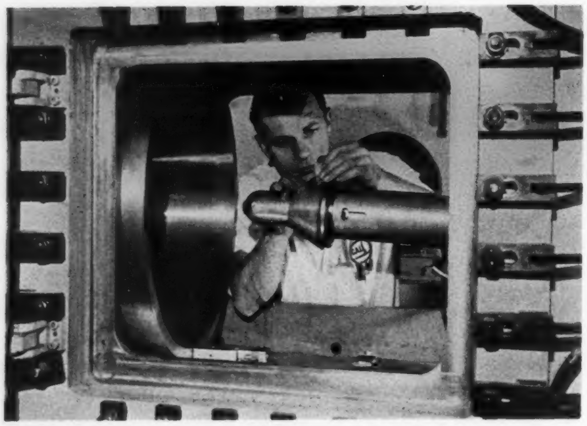


FIG. 4 — Technician installing model in test section of tunnel.

nearly to rest, delaying its passage through the nozzle and increasing the test duration.

If, at the interface between the driven air and the driver gas, the acoustic compliance of the two gases is the same, an increase in the time of steady supply conditions can be attained. This requires that the driver gas possess proper initial conditions of density and speed of sound. Thus, the driver gas has been *tailored* to the proper conditions to increase the running time of the tunnel.

Two gases with attractive properties and which will tailor with air are helium and hydrogen. Hydrogen was excluded as being too difficult to handle because of the extreme precautions required. Helium, on the other hand, is both limited in supply and expensive. Fortunately, it was possible to incorporate in the design a means of recovering and reusing the helium. After a run, the helium-air mixture is compressed to 2500 psi and then passed through a helium purifier. The purifier operates from a charge of liquid nitrogen, which is at a temperature of −322°F., and is a refrigerator which literally freezes the air out of the mixture. Helium, with the lowest liquefaction temperature of any gas, remains a gas and is discharged from the apparatus 99% pure to be further compressed and either stored or loaded into the driver for another run.

Driver Gas Heated

Next, provision was made to vary the temperature of the driver gas. The speed of sound in a gas varies with its temperature and thus provides a means of tailoring the driver gas for the range of test conditions designed into the tunnel. The necessary temperature range was from room temperature to 1000°F. Because of the large metal content of the driver tube, it would be impossible to keep the 1000° helium from cooling unless the tube were also at that temperature. This problem was resolved by enclosing the driver tube in a heating jacket thermostatically controlled to provide a constant temperature at any temperature up to 1000°F. A differential heating capacity at the top and bottom of the tube prevents the few degrees variation in temperature caused by convection currents within the heater jacket. Even a small temperature difference in the tube might result in misalignment with the driven tube.

Description of the Tunnel

An internal diameter of eight inches was chosen as a reasonable size for the shock tube. The driven tube is limited to 60 feet, about 100 times its diameter. Because lengthening the tube attenuates the shock wave, and results in reduction of heating and compression of the air, this limit was placed on the tube length. A 30-foot driver length is required for a 60-foot driven tube; however, only 20 feet of this length was heated. The volume of gas in 30 feet of driver tube at 400 atmospheres is approximately 5000 cubic feet of helium at standard pressure. This requires a compressor large enough to enable the tunnel to be run at the design rate of eight runs per day.

A shock tube this size will process enough air to drive a 2-foot diameter nozzle at the required Mach number range. In order for the air to flow into the nozzle quickly at the start of a run, the nozzle and receiver tank downstream must be evacuated to a low pressure. A mechanical vacuum pump and two oil-diffusion high-vacuum pumps were provided capable of evacuating the 1100 cubic foot system to five millionths of an atmosphere in 20 minutes. The driven tube and nozzle are separated by a thin diaphragm which breaks upon impact of the shock wave.

The diaphragm between the driver and driven tube must withstand over 300,000 pounds. A scheme is employed wherein two diaphragms are used with a small space between them. The pressure between the diaphragms is at half the pressure of the driver. Thus, each diaphragm needs to withstand only half the driver pressure. To break the diaphragms and initiate a run, the inter-diaphragm pressure is merely increased to full driver pressure. The diaphragms, scribed with a cross to cause them to petal back uniformly, (Figure 3), break in rapid succession. For a 6000 psi cold helium driver, copper discs are used. For a 6000 psi hot driver, stainless-steel discs must be used.

The driver and driven tubes are held together at the diaphragm station with a nut. While this nut can be tightened to hold the tubes together, the diaphragms must also be clamped to prevent their being extruded into the tube after the nut is tightened. An annular hydraulic piston built into the tube provides a million pounds of clamping force after the nut is tightened.

When the diaphragms break, the driver gas pressure is suddenly acting on only the upstream end of the driver. Were this unbalanced force not compensated for by securely mounting the tunnel to a solid block of cement set in the floor, the tube would accelerate much as a rocket and travel several feet before recoiling. The structure includes two recoil pistons which lighten the load by allowing the 20-ton tunnel to recoil up to a half inch.

Because each research facility serves as a prototype for another of more advanced design, the successful operation of each phase of CAL's 24-inch hypersonic tunnel lends confidence that more advanced concepts can be applied. Consequently, preliminary plans are already being formed for the next-generation tunnel, but many questions of hypersonic flight and of tunnel design will be answered in the tunnel now operating.

A Low Range Airspeed Indicator for HELICOPTERS

by ELLIS R. SPAULDING

There are very few pilots who can't tell whether they are coming or going. Determining the direction or measuring the airspeed of a conventional airplane is a relatively simple matter, but for the helicopter pilot these are more difficult problems. Despite the helicopter's nearly 20 years of flight, there is no instrument which can determine accurately the relative air velocity of the helicopter at low speeds!

"An important problem to aviation in general is the devising of accurate, reliable and durable airspeed meters and other aeronautic instruments for the navigation and control of aircraft." This statement, contained in the First Annual Report of the NACA[(1)] published in 1915, is as valid today as it was forty-five years ago. From the inception of aviation, man has found it desirable and often essential, to have instruments to help him navigate and control his aircraft. On his first flight Orville Wright carried a Richard anemometer, not to measure the speed of his airplane, but to determine the distance it travelled. From that day on there has been a continued effort to provide more and better instruments for aircraft.

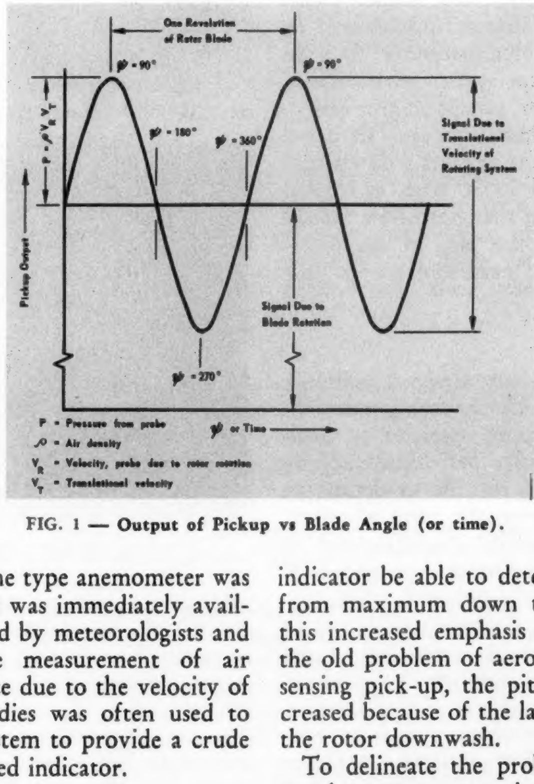


FIG. 1 — Output of Pickup vs Blade Angle (or time).

In the early days of aviation airspeed indicators of many types and varieties were prevalent. The cup or vane type anemometer was often used, no doubt because it was immediately available, having long been employed by meteorologists and mechanical engineers for the measurement of air velocity. The aerodynamic force due to the velocity of air over various shapes of bodies was often used to deflect a spring and pointer system to provide a crude type of remotely located airspeed indicator.

Pitot Tube Used Early

Toward the end of the first decade of flight, remote-sensing, mechanical flight instruments began to appear in the cockpit. From that time on airspeed instruments sensing some form of dynamic pressure due to airspeed gained in popularity. Initially the combination of pitot tube and venturi was used extensively, probably because it produced large differential pressures, thus easing the problem of building the differential pressure gage that was used as the airspeed indicator. Gradually, as the speeds of aircraft and the dynamic head associated with the speed increased, the need for the venturi disappeared and the pitot-static tube became the standard means of sensing the speed of aircraft. This is not to imply that there are not problems associated with the accurate measurement of airspeed by means of the pitot-static tube, but rather that it has been universally accepted as the standard sensor.

This was the state of the art when, on May 20, 1940, Igor Sikorsky first publicly demonstrated his strange looking VS-300 helicopter. It was presumed that providing proper instruments for such a machine would be relatively simple, since man had been flying for nearly forty years and considerable progress had been made in providing adequate instruments for aircraft. In the main this was true. With minor changes and adaptations, standard aircraft instruments were found to be adequate for this new machine.

In the case of the measurement of airspeed, however, a new problem arose and an old one was accentuated. Because this new machine was capable of hovering, it was desirable that the airspeed indicator be able to determine accurately *all* airspeeds from maximum down to zero. Simultaneously, with this increased emphasis on accuracy at low airspeeds, the old problem of aerodynamic interference with the sensing pick-up, the pitot-static tube, was greatly increased because of the large area under the influence of the rotor downwash.

To delineate the problem more specifically, let us associate some approximate values with the problems just mentioned. First consider the speed range from 0 to 100 mph. If we were to measure speeds as low as one mph with the conventional pitot-static tube system, we would require a differential pressure indicator which would respond with a pointer movement of one mph for an applied differential pressure of 0.0005 inch of water. At a speed of 100 mph the indicator would be subjected to a differential pressure 10,000 times this value. Thus it is apparent that the use of the standard pitot-static tube for measuring speeds of 1 to 100 mph requires, for an airspeed indi-

(1) First Annual Report of the NACA to Congress, dated December 9, 1915.

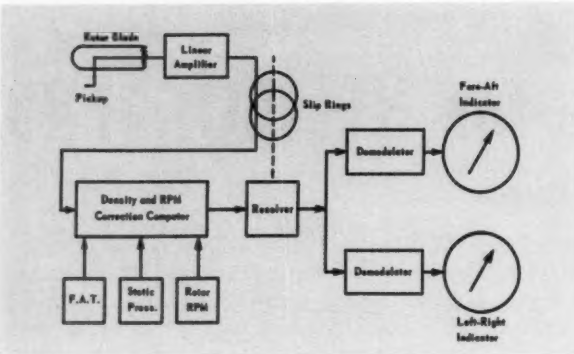


FIG. 2 — **Longitudinal and Lateral Airspeed Indicator for Helicopters.**

cator, a differential pressure gage with an accuracy and resolution of one part in ten thousand or 0.01%. Such accuracy, over the required pressure range, is currently difficult to attain, even under laboratory conditions.

Now consider the aerodynamic interference effect on the conventional airspeed indicator installation. In order to provide the lifting force necessary to keep the helicopter in the air, its rotor system is necessarily large. Normally the rotor system sweeps an area covering essentially all of the helicopter fuselage. In order to create its lift, the rotor system imparts a downward velocity to the air of as much as 50 mph in certain instances. It is hardly surprising that downflow velocities of such magnitude across the face of the pitot-static tube preclude accurate measurements at low forward airspeeds.

Reliable Indicator Needed

One of the basic needs for a low airspeed indicator is in flight testing helicopters. The hovering performance of the helicopter is extremely sensitive to small values of airspeed. Consequently, for consistency in this type of testing, one should be able to determine accurately the airspeed at and near the point of hover. Measurement of helicopter stability characteristics at low speeds likewise requires accurate knowledge of airspeed. The lack of a reliable indicator for low forward speeds was, and still is, a contributing factor to the unsatisfactory all-weather flight capability of the helicopter[2]. In addition, the helicopter's usefulness in certain military applications such as carrier landing, ASW missions and rescue operations would be considerably enhanced under certain operating conditions if its airspeed could be accurately ascertained at low values.*

To surmount the difficulties associated with the commonly used pitot-static system for the measurement of airspeed of the helicopter, the two fundamental problems of low sensitivity at low airspeeds and aerodynamic interference effects must be overcome.

Let us imagine for a moment the conventional pitot-static tube system physically transferred to the tip of a rotating helicopter blade. Certain properties of such an installation are readily apparent. First, the sensing element is now removed as far as possible from any effects of air flow over the fuselage, while still retaining its mounting on the basic aircraft. Second, the angle-of-attack changes on the pitot-static tube due to downflow from the rotor are minimized because the downflow of air caused by the rotor system is now insignificant compared to the high (400 mph) speed of the rotor tip in rotation. It is also true, although not apparent, that the pressure available to operate a sensor with the pitot-tube mounted on the rotating blade is greatly increased. For a typical helicopter the pressure available is in the order of 0.6 inch of water for a 1 mph forward speed instead of 0.0005 inch of water previously mentioned for the conventional type of pitot-static tube installation. Hence, at an airspeed of 1 mph, over 1200 times as much pressure is available for use in operating a sensing device.

Probe on Rotor Blade

It has already been implied that the system developed at Cornell Aeronautical Laboratory makes use of a

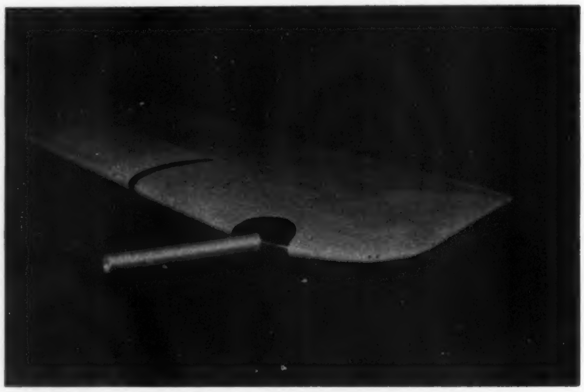


FIG. 3 — **Pressure probe installed on rotor blade tip.**

pressure probe on the tip of a rotor blade. The pressure probe used is a single pitot tube, sensing total head pressure (Fig. 3). To envision the operation of the system, assume the helicopter is hovering stationary with respect to the air surrounding it. In this condition the total pressure sensed by the probe will be a constant value produced by the steady speed of the pitot tube on the rotor blade. Now consider the helicopter moving forward through the air. As the blade carrying the probe moves forward in the direction of motion of the aircraft, the relative air velocity with respect to the sensing probe is increased, resulting in increased pressure in the probe. Conversely, as the blade rotates toward the rear of the aircraft, the relative air velocity is diminished and the pressure is decreased. Thus there is set up at the sensing probe a periodic pressure fluctuation with a frequency equal to rotor revolutions per second (Fig. 1). It can be shown that the amplitude of this pressure fluctuation

[2] Instrument Requirements for All-Weather Helicopter Flight by R. F. Bohling, *IRE Transactions-Aeronautical and Navigational Electronics*, September, 1955.

* Since 1953, the U. S. Navy has sponsored flight tests of the original instrument and development of an improved instrument working on the same basic principle.

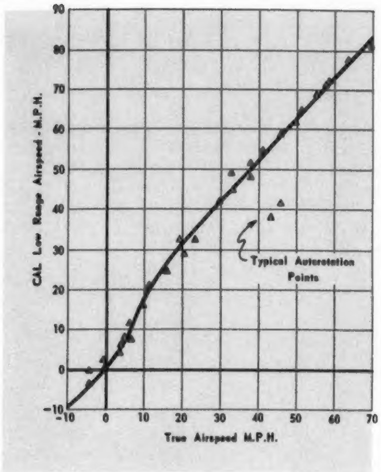


FIG. 4 — **Flight Calibration — CAL Airspeed Indicator.**

is a measure of the airspeed of the helicopter. It can also be demonstrated that the phase relationship of this fluctuation, with respect to the angular position of the instrumented blade, indicates the translational direction of motion of the helicopter relative to the air surrounding it. In the indicator system the pressure fluctuation containing airspeed magnitude and direction information is converted to an electrical signal. This signal is then resolved into two orthogonal components: the magnitudes of the airspeed in the direction of the longitudinal and the lateral axes of the helicopter.

Corrections Yield True Airspeed

The mathematical relationship between the fluctuating pressure sensed by the pressure probe and the airspeed of the helicopter is such that corrections must be made within the indicator system. Those corrections must account for changes in speed of rotation of the helicopter blades and changes in the density of the air in which the helicopter is flying if the airspeed is to be correctly indicated. The manner in which the corrections are introduced into the system will result in true airspeed rather than indicated airspeed. The presentation to the pilot is made on two separate indicators: one reading the speed component in the direction of the helicopter's longitudinal axis; the other showing the speed along the lateral axis. As an alternate presentation, both components can be displayed on a single cross-pointer type instrument.

The complete system (Fig. 2) was installed in a Sikorsky XH03S-2 helicopter and means were provided to monitor the performance of the airspeed system by recording pertinent parameters on an oscillograph.

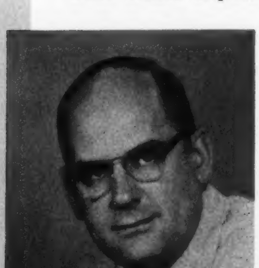
One of the most important of these parameters was a reference true airspeed for calibration purposes. Satisfactory references were found in the ship's standard airspeed system down to about 40 mph and a special anemometer mounted on a long boom for speeds of 55 mph down to about 6 or 7 mph in forward speed. No accurate, direct method for calibrations at very low forward air speeds or rearward air speeds has yet been found. A typical calibration plot for the Cornell Airspeed Indicator system is shown in Figure 4.

Two phenomena which have defied a satisfactory explanation to date are: (1) the consistently low calibration points when the helicopter is in auto-rotation, and (2) the slight non-linearity of the calibration curve in the region of zero to 25 mph. Although many theories have been advanced to explain these phenomena, and many have been checked by flight or ground tests, their secret remains undiscovered.

ABOUT THE AUTHORS

JAMES F. MARTIN, author of "New Tool For Research," is assistant head of the Laboratory's Applied Hypersonic Research Department.

A graduate of the University of Minnesota in aeronautical engineering, Mr. Martin's first assignment was in structural test engineering with the Boeing Airplane Company. On joining Cornell Aeronautical Laboratory two years later as assistant research aeronautical engineer, he was made operations engineer in the Transonic Wind Tunnel Department. Later, promoted to head of the tunnel's Equipment Branch, his duties included instrumentation and maintenance.



Late in 1957, Mr. Martin became concerned with preliminary work leading to the design and construction of the 24-Inch Hypersonic Shock Tunnel and, after completion, with its operation and testing.

Mr. Martin is a member of the Institute of the Aeronautical Sciences.

ELLIS R. SPAULDING, author of "A Low Airspeed Indicator for Helicopters," has been associated with aeronautics, flight testing and aircraft instrumentation for over twenty years.

Ten of those years he has been with the Laboratory's Flight Research Department both as head of the department's Mechanical and Electrical Branches, and more recently as Administrative Engineer.

Prior to joining Cornell Aeronautical Laboratory, Mr. Spaulding spent over ten years with the Chance Vought Division of United Aircraft both as Aerodynamics and Flight Test Engineer, and as supervisor of Flight Test Planning in charge of all experimental flight test engineering including aircraft instrumentation.

He was also a staff engineer for the Revere Corporation, manufacturers of aircraft engine instrumentation.

A graduate of Worcester Polytechnic Institute, Mr. Spaulding served on the faculty of his alma mater for five years as instructor in Mechanical Engineering.

Mr. Spaulding is a member of the Institute of the Aeronautical Sciences, the American Society of Mechanical Engineers, the Instrument Society of America, and Sigma Xi.

RECENT CAL PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Supplies of some publications are limited, and those marked with an asterisk may be distributed only within the United States. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"AN INTRODUCTION TO THE TIME-MODULATED ACCELERATION-SWITCHING ELECTROHYDRAULIC SERVOMECHANISM," Murtaugh, Stephen A., Jr.; Reprinted from the A.S.M.E. Transactions, Series D, Journal of Basic Engineering, Vol. 81, No. 2; 1958; 9 pages.

A discussion of a new concept in electrohydraulic control is presented in this paper. The technique used has resulted in increased reliability, excellent servo valve resolution, negligible center-shift due to temperature extremes, and near infinite pressure-gain characteristics.

"GASDYNAMICS OF A WAVE SUPERHEATER FACILITY FOR HYPERSONIC RESEARCH AND DEVELOPMENT," Weatherston, Roger C.; Smith, William E.; Russo, Anthony L.; and Marrone, Paul V.; CAL Report No. AD-1118-A-1; February 1959; 133 pages.

This report treats the wave superheater, a unique device to produce a continuous, supersonic flow of uncontaminated air or other gases at temperatures and pressures needed for realistic hypersonic testing in the laboratory. The fundamental principles of wave superheater design and operation are developed. In particular, the gasdynamic and heat transfer aspects of one version, which is designed to generate 9000°R in uncontaminated air, are discussed.

"APPLICATION OF ROUTH'S ALGORITHM TO NETWORK-THEORY PROBLEMS," Fryer, William D.; Reprinted from the IRE Transactions of the Professional Group on Circuit Theory, Vol. CT-6, No. 2; June 1959; 6 pages.

Routh's criterion uses a very efficient computational method, or algorithm, that has been found to be applicable to a number of other important problems of circuit theory. Among these applications are finding common factors of polynominals, computing Sturm's function, synthesizing RC, RL, or LC ladder networks by means of continued-fraction expansions, determining RC, RL, or LC realizability of a given immitance function, and analysis of ladder networks.

"AN OUTLINE AND PRELIMINARY ANALYSIS OF THE BASIC PROBLEMS OF ROAD LOADING MECHANICS," Fabian, Gardner J.; CAL Report No. YM-1304-V-1; July 1959; 44 pages.

An analysis is presented of the basic problems involved in the development of a comprehensive treatment of road loading mechanics. The complete road loading system is defined and its various component elements are discussed. The development of a realistic mathematical model of the vehicle as the road loading element is accomplished. The significance of the model response to certain inputs is discussed. Conclusions and recommendations are drawn from the complete study.

"SHOCK TUBE STUDIES OF REACTION KINETICS OF ALIPHATIC HYDROCARBONS," Glick, Herbert S.; Reprinted from the Seventh Symposium (International) on Combustion; 1958; 10 pages.

The CAL single-pulse shock tube has been used to study the reactions which take place when three aliphatic hydrocarbons are heated to high temperatures, either alone or in the presence of oxygen-bearing substances such as water vapour.

"A SYSTEM FOR IMPROVING THE PERFORMANCE AND SAFETY OF HELICOPTERS POWERED BY TURBOSHAFT ENGINES," Osofsky, Irving B.; Reprinted from the American Helicopter Society, Proceedings of the 15th Annual National Forum; May 1959; 13 pages.

Gas turbines, the main power plant for existing and proposed helicopters and VTOL vehicles have a number of shortcomings including: power loss on a hot day; power loss with increasing altitude; difficulty of and long time required for starting; poor response to throttle change and lack of emergency power.

"STUDY OF HUMAN KINEMATICS IN A ROLLED-OVER AUTOMOBILE," Shoemaker, Norris E.; CAL Report No. YM-1246-D-1; June 1959; 63 pages.

Results of a research program in the field of automobile roll-over crash safety under the sponsorship of the Liberty Mutual Insurance Company of Boston, Massachusetts are presented. This program was directed toward controlling and reducing body injuries to the occupants during a roll-over type of accident. The automobile roll-over crash safety project was to determine, by experimental tests and the use of time-motion study, the kinematics of the human body in relationship to the interior of the car body when a roll-over condition was imposed upon the vehicle.

The following reports are available only through ASTIA to organizations holding government contracts. Please direct your request to the Commander, Armed Services Technical Information Agency, Arlington Hall Station, Arlington 12, Va. Request ASTIA Reports Nos. 201868 and 142184, respectively.

"THEORY OF CAMBERED JOUKOWSKY AIRFOILS IN SHEAR FLOW," Sowyrda, Alexander; CAL Report No. AI-1190-A-2; September 1958; 26 pages.

A development of two-dimensional airfoil theory is presented which extends the existing theory of symmetrical Joukowsky airfoils in uniform shear flow to cambered airfoils. Some numerical results are given.

"ADDITIONAL FLIGHT EVALUATIONS OF VARIOUS LONGITUDINAL HANDLING QUALITIES IN A VARIABLE-STABILITY JET FIGHTER," Chalk, Charles R.; CAL Report No. TB-1141-F-1; March 1958; 47 pages.*

An F-94 jet fighter has been modified by the Cornell Aeronautical Laboratory to provide variable longitudinal stability and control characteristics, thus permitting in-flight variations of the longitudinal handling qualities. A variety of short period dynamics, stick force gradients, and stick displacement gradients were evaluated. The qualitative ratings of longitudinal handling qualities are shown as areas of varying degrees of the pilot's acceptance of these characteristics.

1959 Annual Report available upon request. Supply is limited.